Assessment of Coastal Wind Energy Resource,Two Locations in Algerian East

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Abstract

The aim of this paper is to investigate the monthly and seasonal variation of the wind resource in term of wind energy potential using the wind speed data collected in the last decade for the meteorological stations at twocoastal locations situated in Algerian East. After the study of temporal Weibull parameters, we proceeded to give a correlation between the air temperature and the wind speed. The vertical extrapolation of Weibull parameters and mean wind speed at a height of 50m was made and the analysis of annual energy efficiency, seasonal and monthly was made for wind energy conversion systems of 600kw rated capacity. The results show that El Kala has the highest wind potential with the annual mean wind speed V = 3.7m/s and the annual wind energy production equal to 1.4Gwh/year, while Skikda gives a less potential. The study gives the coastal regions situated in East of Algeria with a little wind potential, where the better wind energy potential is given in coldest months.

Keywords

Wind Resource; Assessment; Algerian East; Mediterranean Climate

Introduction

Generating electricity in North Africa using renewable energy resource has been around for some time now but has recently gained momentum through several plans as Desertec Industrial Initiative, where an export bundled with wind energy is the most feasible option for North African concentrated solar power [1]. Since North African's countries have high levels of direct solar radiation, the aim of these plans is to create new power production capacity bases on renewable energies, especially by solar and wind on the Mediterranean basin [2] even if it is compellingly and apparently economically sensible to harness the resource most at the place it is most readily available [3].

In Algeria, the objectives established by the join-stock company NEAL (New Energy Algeria), focused on raising renewable energy production to 1400 MW in 2030 and 7500 MW at the beginning of 2050. Electrical power will be obtained from solar power plants, which are exclusively solar, or from hybrid solar plants, which also use other forms of renewable or conventional energy, preferably natural gas [4]; recently, Boudghene Stombouli has concluded that there is a considerable potential in Algeria for the utilization of renewable energy sources [5] especially with respect to solar and wind power that produce fewer greenhouse gas emissions [6].

The wind is generated due to the pressure gradient resulting from the uneven heating of earth's surface by the sun. As the very driving force causing this movement is derived from the sun, wind energy is basically an indirect form of solar energy; this means that the wind is driven by the temperature difference [7]. Adaramola et al. concluded their study on the importance to thoroughly carry out intensive and detailed measurements of temperature with direction and wind speed on the targeted site over a defined period and the nature of the topology of the site have to be studied [8]. Soler-Bientz et al. gives the significance of study of the offshore wind and temperature profiles [9]. Recently Lima et al. made an analysis with several meteorological parameters, where air temperature at two levels, 25 and 50m were studied to make wind resource evaluation at Paraiba region in Brazil, concluding that air average temperature has a strong impact on air density value [10].

Concerning Algeria, even if we note with satisfaction the contribution in the actualization of wind map of Algeria adding the study of Hassi R'mel in the South of the country at the wind atlas by Chellali et al. [11], few studies have been conducted to assess wind resource

and the majority of them were focused at the Sahara in South of Algeria[12-17], result to the good wind resource concluded from wind map by Kasbadji[18,19] and Chellali et al. [11] respectively in Adrar and Hassi R'Mel, two regions in Algerian Sahara.

Wind speed is the most important aspect of the wind resource; in fact, Aynuar Ucar et al. shown that the yearly and seasonal variation of long term mean wind speed provides an understanding of the long term pattern of wind speed and also gives confidence to an investor on the availability of wind power in coming years [20].

It is why, in this study, we choose to contribute on temporal wind assessment at two coastal locations in Algerian East, near from the boundaries with Tunisia, and try to confirm the correlation between air gradient temperature and wind speed in this region, knowing that altitude and temperature variations across the country contribute to the amount of wind. For optimal use of wind energy, it is necessary to know the wind speed at heights upward the ground. Since wind speed increases with height, wind energy is usually captured at heights above the height of wind measurements by the National Meteorological Office (ONM), which is 10m. As well, the objective of this work is to estimate average wind speed (annual, seasonal and monthly) at anemometer height by numerical simulation and calculating the average energy generated by the Fuhrländer FL600 wind energy conversion systems of 600kw rated capacity at 50m height hub.

At first we investigate the wind characteristics, using the wind speed data collected in last decade, a study of the temporal variation of Weibull parameters (A and k) and the mean wind speed V was made for whole years, the four seasons and the twelve months year. Vertical extrapolation of wind speed has been made by an empirical model. In the second time, the monthly distribution of Weibull parameters during the studied time period was made to give an eventual correlation between air temperature and wind speed. At the end, we estimate the average energy density recovered by the wind energy conversion systems versus years, seasons and months.

Sites Selection and Weather Data

In this paper, data from twocoastal stations distributed over Algerian East (Fig. 1) have been analyzed. The geographical coordinates of these meteorological stations and the years of measurements are given in Table I.

TABLE 1 GEOGRAPHICAL COORDINATES OF THE DATA COLLECTION STATIONS USED IN THE STUDY

Location	Longitude	Latitude	Altitude (m)	Duration (years)	Measurement years
El Kala	36.90	13	13	03	01/01/2008 31/12/2010
Skikda	36.88	6.95	07	10	01/01/2001 31/12/2010

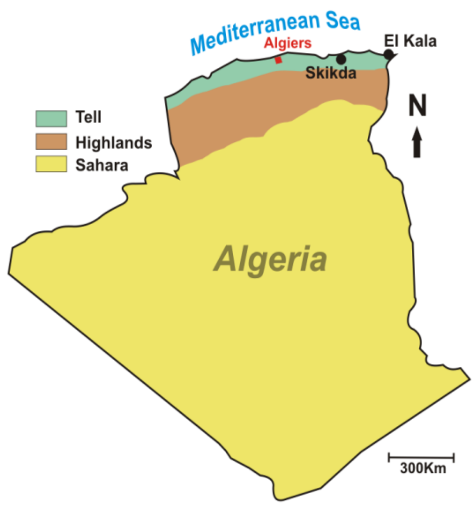


FIGURE 1 MAP OF ALGERIA

Wind Analysis Model

The Weibull function is used to characterize the frequency distribution of wind speeds over time [21]. It is defined by the following equation:

$$f(v) = \left(\frac{k}{A}\right)\left(\frac{v}{A}\right)^{k-1} \exp\left[\left(\frac{v}{A}\right)^{k}\right] \quad ◎◎◎$$

Where f(v), is the probability of observing wind speed v, k is the dimensionless Weibull shape parameter, and A is the Weibull scale parameter.

The average wind speed can be calculated on the basis of the Weibull parameters as given below [22,23]:

$$V_m = A.\Gamma\left(1+\frac{1}{k}\right) \quad (2)$$

Where V_m is the average wind speed, and Γ is the Gamma function.

Wind Power Density

The power of the wind that flows at speed v through a blade sweep area S[m²] as the cubic of its velocity and is given by [24]:

$$P(v) = \frac{1}{2} S \varrho v^3 \tag{3}$$

Where, ϱ[kg/m3] is the air density.

The power available in wind can be calculated as follows:

$$P = \frac{1}{2} S \varrho A^3 \Gamma\left(1 + \frac{3}{k}\right) \tag{4}$$

Extrapolation of the Weibull Parameters at Hub Height

If the wind distribution is desired at some height other than the anemometer level, the advantage of the use of the Weibull distribution is that A and k values can be adjusted to any desired height by different relations. According to the literature and responds to the study region, the relation proposed to assess the Weibull scale parameter A_2 at hub height Z_2 is given by the model of Justus [25] expressed by:

$$\frac{A_2}{A_1} = \left(\frac{Z_2}{Z_1}\right)^m \tag{5}$$

Where the power law exponent m is given by:

$$m = \left(\frac{0{,}37 - 0{,}0881.\ln A_1}{1 - 0{,}0881.\ln\left(\frac{Z_1}{10}\right)}\right) \tag{6}$$

And the relation proposed to evaluate the Weibull shape parameter k_2 at hub height is given by:

$$\frac{k_2}{k_1} = \left(\frac{1}{1 - 0{,}0881\ .\ln\left(\frac{Z_2}{Z_1}\right)}\right) \tag{7}$$

Wind Energy Density

Under the above mentioned hypothesis, the electric energy E[kWh] which can be produced per time period t and including the blade sweep area S[m²] is given by [25,26]:

$$E = C_p \frac{1}{2} \varrho S A^3 \Gamma\left(1 + \frac{3}{k}\right) . \frac{t}{1000} \tag{8}$$

With C_p is the power coefficient for each wind turbine.

Air Density

The air density is defined as the mass of a quantity of air divided by its volume. This parameter has a great importance in the estimation of the power density and factors like temperature, atmospheric pressure, elevation and air constituents affect the density of air. So, to calculate the air density we commonly use the following expression [27]:

$$\varrho = 3{,}484 \frac{P}{T} \tag{9}$$

Where P is the air pressure and T is the air temperature.

This law represents a fairly good approximation, especially in regions where large temperature differences can be observed between the different seasons.

Wind Energy Yield Estimation

The monthly, seasonal and annual wind energy potential will be assess using a hypothetical commercialized 600Kw wind energy conversion systems installed at 50m above ground level. Energy calculations requires the wind turbine power coefficient curve, the rotor swept area and hub height. The wind turbine related parameters given by the manufacturer are summarized in Table II.

TABLE 2 WIND TURBINES PARAMETERS

Model	**Fuhrländer FL600**
Rated power (Kw)	600
Rotor diameter (m)	50
Hub height (m)	50
Swept area of rotor (m²)	1962
Cut-in-wind speed (m/s)	3
Rated wind speed (m/s)	14.5
Cut-out-wind speed (m/s)	19

Results and Discussion

The wind speed data at the two coastal locations (El Kala and Skikda) in Algerian Easthave been analyzed taking into account the monthly and seasonal variations.

The monthly variation of the mean wind speed and the mean power density at 10 and 50m above the ground level are listed in Table III.

For El Kala site, it can be observed that the monthly mean wind speed at 10 m varies between 3.03m/s in August and a maximum value of 5.03m/s in February, while at the hub height the monthly wind speed varies between 4.62 and 7.04m/s. Furthermore, at 10m, the mean power density varies between 30.50w/m² in August and 222.10w/m² in February.

TABLE 3 MONTHLY VARIATIONS OF MEAN WIND SPEED AND POWER DENSITY AT THE STUDIED STATIONS

	Stations	El Kala				Skikda			
	Elevation	10		50		10		50	
	Parameters	V[m/s]	$P[w/m^2]$	V[m/s]	$P[w/m^2]$	V[m/s]	$P[w/m^2]$	V[m/s]	$P[w/m^2]$
Months	January	3,74	83,01	5,48	214,65	3,81	53,05	5,65	156,95
	February	5,03	222,10	7,04	493,00	3,48	41,44	5,22	126,50
	March	4,03	94,05	5,86	242,28	3,38	42,40	5,08	126,95
	April	4,20	82,80	6,12	225,09	3,10	30,90	4,73	97,62
	May	3,71	65,12	5,48	179,65	2,92	22,30	4,51	75,35
	June	3,60	55,61	5,34	158,35	3,09	24,14	4,74	81,70
	July	3,06	44,12	4,62	125,35	2,96	21,03	4,57	72,74
	August	3,03	30,50	4,63	95,78	3,04	21,72	4,69	75,33
	September	3,31	48,30	4,96	138,25	3,02	23,65	4,64	79,74
	October	3,77	90,05	5,51	228,44	3,14	28,73	4,79	93,13
	November	3,70	57,23	5,49	163,64	3,69	47,41	5,50	142,90
	December	4,09	103,89	5,93	261,96	4,08	74,40	5,97	205,85

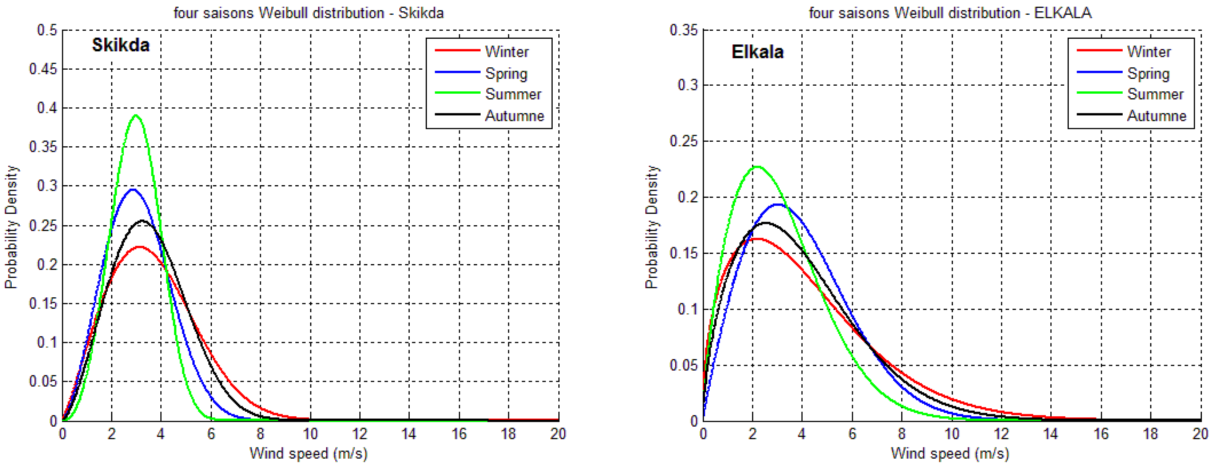


FIGURE 2 SEASONAL WEIBULL WIND DISTRIBUTION AT 10M

For Skikda site, it can be observed that the monthly mean wind speed at 10 m varies between 2.92m/s in May and a maximum value of 4.08m/s in December, while at the hub height the monthly wind speed varies between 4.51 and 5.97m/s. Furthermore, at 10m, the mean power density varies between 21.03w/m² in July and 74.40w/m² in December.

The seasonal Weibull wind distribution at 10m for the two studied sites is shown in Fig. 2 and the seasonal variation of the mean wind speed and the mean power density at 10 and 50m above the ground level are listed in Table IV. For the studied sites, the minimum value of mean wind speed at 10m is in Summer season with 3.13m/s in El Kala and 2.99 in Skikda; while the maximum value of mean wind speed is in Winter season with 4.13m/s in El Kala and 2.99m/s in Skikda. Furthermore the mean power density at 10m varies between 40.95 and 118/13w/m² for El Kala site and between 21.64 and 52.32w/m² for El Kala site.

From Fig. 2 we note that for El Kala, the wind speed covers the large range of variation in Winter and Autumn seasons, and which reaches [0–15m/s], whereas in Spring the higher range is limited at 12m/s and in Summer it does not exceed 10m/s. For Skikda, the wind speed covers a less range of variation for all seasons where the higher range limit does not exceed 10m/s in Winter season.

TABLE 4 SEASONAL VARIATIONS OF MEAN WIND SPEED AND POWER DENSITY AT THE FOUR STATIONS

Elevation	10m		50m	
Parameters	*V[m/s]*	*P[w/m²]*	*V[m/s]*	*P[w/m²]*
El Kala				
Autumn	3,92	86,53	5,73	225,64
Winter	4,13	118,13	5,96	288,49
Spring	3,88	69,78	5,70	192,39
Summer	3,13	40,95	4,73	119,89
Skikda				
Autumn	3,52	42,17	5,28	128,79
Winter	3,66	52,32	5,44	152,66
Spring	3,09	28,04	4,72	90,90
Summer	2,99	21,64	4,61	74,51

TABLE 5 ANNUAL VARIATIONS OF MEAN WIND SPEED AND POWER DENSITY AT THE FOUR STATIONS

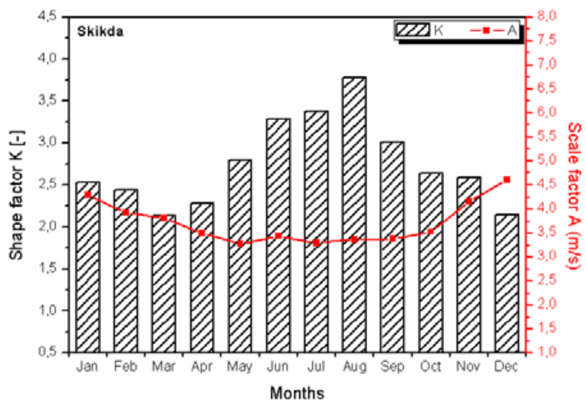
	Elevation	10m		50m	
	Parameters	*V[m/s]*	*P[w/m²]*	*V[m/s]*	*P[w/m²]*
Stations	**El Kala**	3,76	75,53	5,52	201,01
	Skikda	3,30	35,97	4,99	111,79

The annual wind speed frequencies with fitted Weibull distribution at 10m is shown in Fig. 3 and the annual wind characteristics at 10m and at the hub height (50m) are shown in Table V for all two stations.

In Fig. 3, histograms of the wind speed observations are shown at the selected sites with fitted Weibull frequency function, we note the tiny percentage of low wind speed in each studied site, less than 1m/s with 4.5% for El Kala and1% for Skikda. The wind speed covers the larger range of variation in El Kala, and which reaches [0–13m/s], followedby Skikda which reaches [0–8m/s].In suitability with the monthly and the seasonal studies, the results at 10m from Table V give the better annual mean wind speed for El Kala with a value equal to 3.76m/s followed by Skikda with 3.30m/s.

Fig. 4 represents the distribution of both Weibull parameters during the studied time period; the analysis gives the greatest shape parameter kin August for El Kala andSkikda with respectively 2.15 and 3.78; the worst value in Februaryfor El Kala site with 1.45 and in March for Skikda with 2.13. The analysis gives also a good scale parameter Ain coldest months for the two studied site with a greatest value equal to 5.55m/s in February for El Kala, and in December with 4.61m/s for Skikda.

To estimate the energy output of the wind turbine, a procedure was developed. So, in every time step, the power exponent and the power output of wind turbine are estimated. The monthly assessment of wind energy produced by the wind turbine 600Kw rated power is shown in Fig. 5, the seasonal assessment in Fig. 6 and the annual assessment in Fig. 7 for the two localizations.



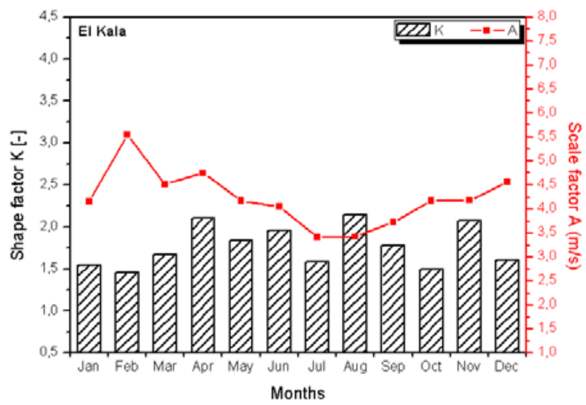


FIGURE 4 MONTHLY WEIBULL DISTRIBUTION PARAMETERS AT 10M

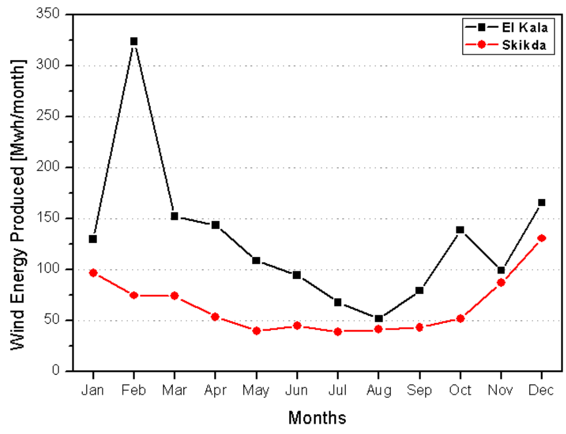


FIGURE 5 MONTHLY WIND ENERGY PRODUCED RESULTS

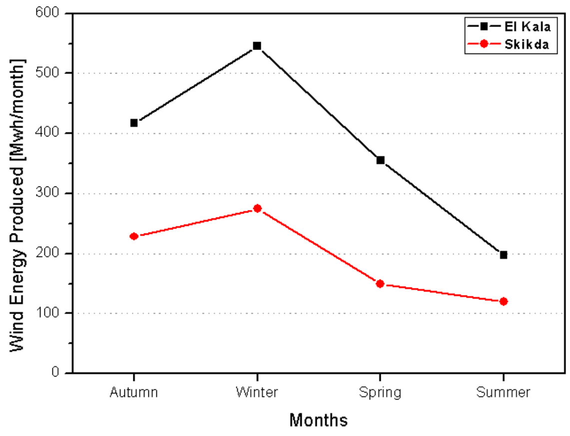


FIGURE 6 SEASONAL WIND ENERGY PRODUCED RESULTS

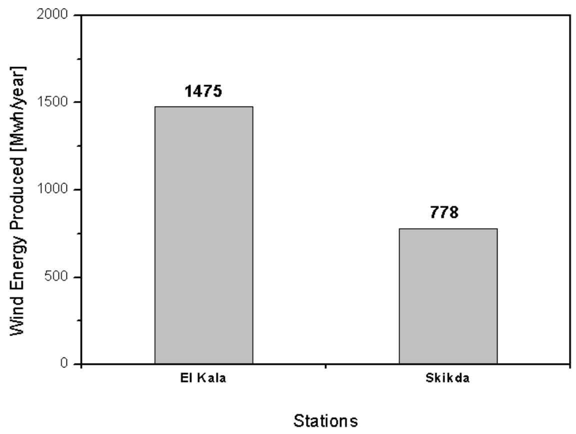


FIGURE 7 ANNUAL WIND ENERGY PRODUCED RESULTS

In adequacy with the precedents results, from (Figs. 5, 6 and 7) the analysis gives El Kala situated in extreme North East of Algeria as the better site, dominates fully all temporal analysis with an annual wind energy production equal to 1.4Gwh/year. Skikdais behind with an annual energy production equal to 0.7Gwh/year.

Conclusion

Through this study, the monthly, seasonal and annual Weibull parameters, mean wind speed and wind power densities are determined at a height of 10 and 50m in monitoring sites at twocoastal locations situated in AlgerianEast, in order to provide information of wind resources. This study gives a potential correlation between wind speed and air temperature in the two studied locations where El Kala site gives in this analysis the better wind potential with an annual mean wind speed V = 3.7m/s at 10m. Further assessment of the monthly, seasonal and annual wind energy output of a wind turbine 600Kw rated power have been done at the two sites. It can be concluded that El Kala has the highest wind potential, followed by Skikda which gives a lower potential. In suitability with high air temperature, where the better wind energy potential is given in coldest months in Winter, the present study leads to assess fully the wind potential in Coastal regions, open to Mediterranean Sea, by setting up much more monitoring meteorological points, and solicits thereafter an eventual feasibility of a wind park project, onshore of offshore.

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